DETERMINANTS OF CYCLIC SEDIMENTATION IN POTTSVILLE ROCKS NEAR DUNDEE, OHIO

HENRY H. GRAY

Indiana Geological Survey, Indiana University, Bloomington, Indiana

INTRODUCTION

A large lenticular body of sandstone occupies the middle part of the Pottsville formation (early Pennsylvanian age) in a northeast-southwest belt approximately a mile wide through Dundee, northwestern Tuscarawas County, Ohio (fig. 1). This sandstone was first identified as the Massillon sandstone by Newberry (1874, chart 2). The present study was undertaken to determine the extent, lithologic character, stratigraphic relations, and origin of this sandstone and associated rocks. Within the 51-square-mile area of study, approximately 120 stratigraphic sections were measured. Sections in surrounding areas yielded supplementary information but were not used directly in the analytical work.

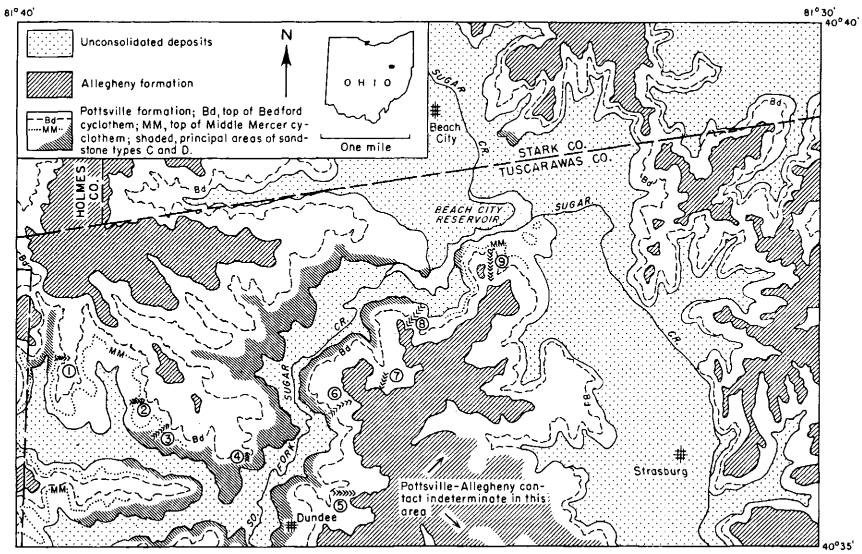

FIGURE 1. Generalized geologic map of area studied. Numbered rows of chevrons indicate locations of measured sections illustrated in figures 4 and 5. Base modified from Navarre 15-minute topographic quadrangle map of U. S. Geological Survey.

Field work for this study, most of which was supported by the Ohio Division of Geological Survey, was done principally in the summers of 1951, 1952, and 1953. Results were presented as a dissertation in partial fulfillment of the requirements for the degree Doctor of Philosophy at The Ohio State University (Gray, 1954).

STRATIGRAPHIC SUBDIVISION AND NOMENCLATURE

Traditionally, formations of Pennsylvanian age in eastern Ohio are identified with reference to key beds, most of which are thin coals or limestones. Thus the boundary between the Pottsville formation and the overlying Allegheny is placed at the base of the Brookville coal; where this coal bed, its associated underclay, and the overlying Putnam Hill limestone, are all absent, the boundary between these formations, as presently defined, cannot be determined (fig. 1). Other coal and limestone beds, some underclays, and conspicuous bodies of sandstone are also named; these, being parts of formations, have essentially the status of members, but are rarely accorded this recognition specifically.

The principal named members that are recognized in the Dundee area are listed below in stratigraphic order:

Allegheny formation	Middle Kittanning (No. 6) coal	
	Lower Kittanning (No. 5) coal	
	Putnam Hill limestone Brookville (No. 4) coal	
Pottsville formation	Tionesta 3 coal	
	Tionesta 2 coal	
	Tionesta 1 coal	
	Tionesta (No. 3b) coal	
	Upper Mercer limestone and chert Bedford coal	
	Upper Mercer (No. 3a) coal	Stratigraphic range of the Massillon sandstone
	Lower Mercer limestone Middle Mercer coal	
	Flint Ridge (?) coal	
	Vandusen (?) coal	
	Bear Run (?) coal	

Many of the coal beds are of small extent, and the Massillon sandstone in different places occupies any part, all, or none of its indicated stratigraphic range; therefore the sequence of beds listed is not entirely exposed in any single section. The coals here called Tionesta 1, 2, and 3 are of very small areal extent and are so designated informally to avoid proposing formal names that might have little value elsewhere.

The Pottsville formation is here divided into several units for purposes of mapping, correlation, and discussion. Each of these units extends from the top of a named coal bed or equivalent stratigraphic position to the next such horizon above. The term *cyclothem* (Wanless and Weller, 1932) is here adopted, with modifications, as the generic name for these rock units. Cyclothems consist of many sedimentary members arranged in a distinctive sequence, with similarly constituted units above and below. Of the several possible places at which boundaries between cyclothems may be placed, the top of the coal is here chosen because this contact is convenient and recognizable over a wide area. As thus defined, the cyclothem can be a useful map unit.

The sequence of members recognized in Pottsville cyclothems in this area includes, in descending order:

8. Coal
7. Underclay or mudstone
6. Gray or olive-gray shale
5. Various types of sandstone
4. Gray or olive-gray shale
3. Sedimentary iron ore and (or) chert (flint)
2. Limestone, locally cherty
1. Thin gray or black shale

Because alternate lithologic types occur in most of the members, it is impossible to find all known lithologic types in a single vertical section. The sequence presented above is assembled from a large number of correlated measured sections and is, therefore, a synthetic, idealized representation.

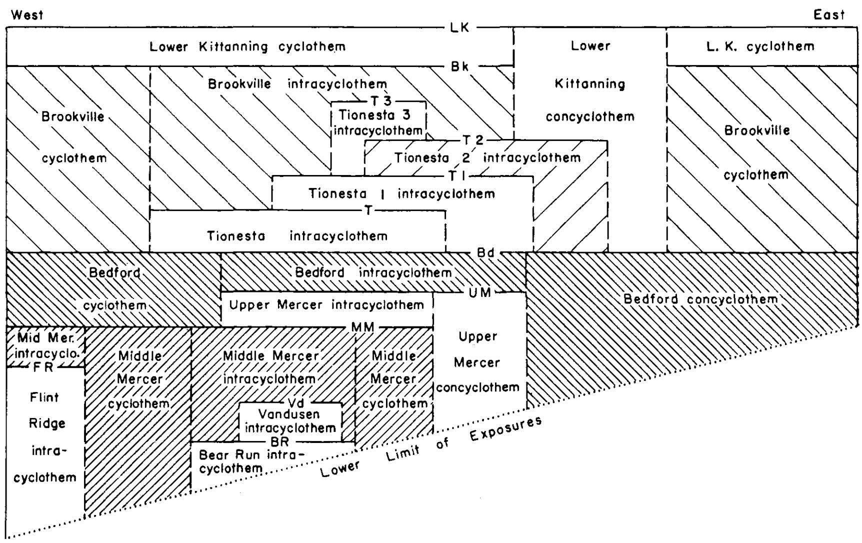

FIGURE 2. Diagram showing nomenclature of cyclic units in Pottsville formation of Dundee, Ohio, area. Solid horizontal lines are tops of named coal beds or stratigraphically equivalent horizons. Dashed vertical lines indicate lateral limits of named cyclic units. Diagram is approximately oriented on basis of available data but is not drawn to scale nor along any particular line of section.

The members most commonly represented are numbers 8 and 7, the coal and underclay. Next most frequent are the sandstones of member 5. Shales occur mostly in cyclothems that lack the sandstone; somewhat less commonly, shales underlie or overlie sandstones and occupy positions 4 or 6. Limestones of member 2 and shales of member 1 are fairly well represented, but iron ore or chert of member 3 is rare. Clastic members 4, 5, and 6 are relatively thick and constitute approximately 85 percent of most of the cyclothems of this area. The underclay-coal-black shale-limestone-chert-sedimentary iron ore sequence is an essential feature of cyclothems. If none of the units of this sequence are present, cyclothems, as here identified, cannot be distinguished.

Where additional distinctive sequences are intercalated locally into a cyclothem, cyclic units identical in kind but subordinate in rank to a cyclothem may be

TABLE 1

Interrelations and relative abundance of the common rock types

(Summarized from 40 representative measured sections aggregating 1,595 ft of exposed rocks)

Rock type	Number of exposures observed	Mean thickness (ft)	Relative abundance (%)	Common underlying rock	Nature of lower contact	Lateral equivalents	Nature of upper contact	Common overlying rock
Sandstones								
type A	15	15	15	type B sandstone gray shale	depositional	unknown	depositional	underclay
type B	5	25	8	mudrocks	erosional	unknown	depositional	type A sandstone
type C	13	20	16	mudrocks	erosional	type D sandstone type E sandstone	depositional	olive-gray shale gray shale
type D	5	25	8	unknown	unknown	type C sandstone type E sandstone	depositional	gray shale
type E	12	20	16	unknown	unknown	type C sandstone type D sandstone gray shale	depositional	mudrocks
Mudrocks								
siltstone	4	4	1	uncertain	uncertain	olive-gray shale?	uncertain	uncertain
olive-gray shale	14	13	12	coal limestone	depositional	unknown	depositional	underclay
gray shale	26	6	10	coal black shale	depositional	type E sandstone	depositional	various
black shale	6	<1	0.3	underclay olive-gray shale coal	depositional	unknown	depositional	gray shale
mudstone	4	7	2	uncertain	uncertain	unknown	depositional	coal
underclay	31	4	8	type A sandstone olive-gray shale gray shale	depositional	unknown	depositional	coal black shale limestone
Chemical rocks								
coal	27	1	2	underclay gray shale olive-gray shale	depositional	unknown	depositional	limestone gray shale
limestone	15	1	1	coal gray shale	depositional	gray shale?	depositional	olive-gray shale
chert	3	<1	0.2	coal underclay	depositional	unknown	depositional	olive-gray shale
iron ores	3	<1	0.1	limestone?	depositional	unknown	depositional	uncertain

recognized. Cyclic units thus resulting from the splitting of cyclothems are called *intracyclothems*, a term that refers to their occurrence within a cyclothem (Gray, 1954, p. 58). They may be sufficiently thick to map, but they are of lesser areal extent than cyclothems.

Where the distinctive sequence in which one boundary of a cyclothem is drawn is locally absent, that cyclothem joins with the adjacent one to form a cyclic unit identical in kind but superior in rank to a cyclothem. Cyclic sequences that thus result from coalescence of cyclothems are called *concyclothems*, a term that refers to their inclusion of the stratigraphic equivalents of parts or all of two or more cyclothems (Gray, 1954, p. 58). In the areas in which they occur they should be mapped in place of the locally unrecognizable cyclothems that they laterally replace.

The cyclothem is the basic cyclic unit in this hierarchical arrangement in much the way that the formation is the basic rock unit. The more widespread cyclic units are defined as cyclothems; intracyclothems and concyclothems are recognized where desirable or necessary. Cyclic units were used in mapping this area at the scale 1:24,000. Cyclothems, intracyclothems, and concyclothems are most conveniently named for the coal beds at their tops (fig. 2).

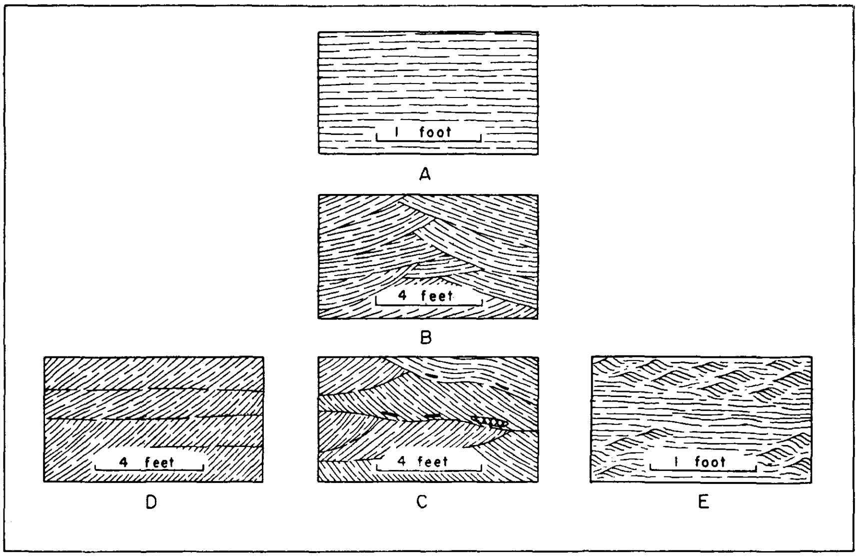

FIGURE 3. Characteristic bedding of the sandstones in Pottsville rocks near Dundee, Ohio. A, even horizontal bedding in type A sandstones; B, concave crossbedding in type B sandstones; C, crossbedding and irregular bedding in type C sandstones; D, uniformly inclined bedding in type D sandstones; E, wavy horizontal bedding in type E sandstones. Approximately to scales indicated.

DESCRIPTION OF ROCK TYPES

Forty representative stratigraphic sections, including nearly 1,600 ft of exposed rocks, were used in compiling the descriptions that follow and the data on interrelations and relative abundance of the various rock types (table 1). A special attempt was made to describe and classify properly the nature of the contacts between rock units as an aid to the interpretation of the depositional history of the area. Contacts here described as depositional include those of transitional, interfingering, or gradational nature, any of which indicate a gradual change in

TABLE 2

Properties of the sandstones

(Averages of many field observations)

		Bedding		Composition				
Type	Color on fresh outcrop	Character	Thickness	Quartz (%)	Clay (%)	Granularity	Sorting	Angularity
A	very light gray	even horizontal	thin	50	50	fine sand	fair	angular
B	very light gray	concave cross	thin to medium	65	35	fine to medium sand	fair	subangular
C	light yellow brown	cross and irregular	medium	75	25	medium to fine sand	good	subangular
D	light gray	uniformly inclined	medium to thick	90	10	medium sand	good	subangular
E	light gray	wavy horizontal	thin to very thin	60	40	very fine sand	poor	megascopically indeterminable

TABLE 3

Properties of the mudrocks

(Averages of many field observations)

		Bedding				
Rock type	Color on fresh outcrop	Character	Thickness	Granularity	Fabric	Inclusions
siltstone	gray to yellow-brown	uneven	thin to very thin	silty	random to parallel	plant fossils, ferruginous concretions
shale	olive-gray	fairly even	very thin	clayey, in part silty	parallel to random	plant fossils, ferruginous concretions
shale	medium gray	even	very thin	clayey	parallel	sparse marine fossils in a few places
shale	black	even	very thin	clayey	parallel	thin coaly streaks, carbonaceous
mudstone	light gray	absent		silty and clayey	random	small root impressions
underclay	very light gray	absent		clayey, in part silty	random	*Stigmaria* in silty underclays

environmental conditions. Sharp contacts that are planar and concordant with bedding both above and below probably represent a break in deposition, a hiatus, but they lack the features distinctive of erosional contacts and in this study are also considered of depositional origin. Contacts here recognized as erosional are characterized by an uneven contact surface that is discordant with bedding of the underlying rock but broadly concordant with bedding of the overlying rock. In some places broken and somewhat worn fragments of the underlying rock or rocks are included in the beds immediately overlying an erosional contact.

Sandstones

Sandstones are the dominant rocks of the exposed part of the Pottsville in this area, as they constitute approximately 63 percent of the rocks examined in detail. The essential minerals of the sandstones are quartz and a group of argillaceous materials here referred to as clay. Morphologic variants of these argillaceous materials that were observed megascopically include (1) sand-size aggregate grains, (2) coatings on quartz grains, and (3) matrix between the grains. Very small quantities of micas, iron oxides, carbonaceous materials, and authigenic quartz as crystal overgrowths were noted in places. For a more complete petrographic description of a typical sandstone in Pottsville rocks of a nearby area, see Gray (1956).

Five sandstone types are here distinguished, mainly on the basis of bedding (fig. 3), but other properties serve to make identification more certain (table 2). It is generally possible to distinguish these types only in good exposures. There are a few borderline examples that do not clearly fall into one class or another, and still fewer that cannot be assigned to any of these five types.

Mudrocks

Mudrocks, in the sense of Ingram (1953), comprise approximately 33 percent of exposed rocks in the sections measured. If mudrocks underlie most of the covered intervals in the measured sections, as field evidence suggests, they may approach, but not exceed, an abundance of 50 percent. Mudrocks are here classified (table 3) on the basis of granularity, bedding character, and color. Fabric is indicated by orientation of mica grains. Mudrocks with parallel fabric show bedding and have a distinct platy to papery fracture; those with random fabric have hackly fracture and lack well-developed bedding. This accords with the findings of Ingram (1953).

Chemical Rocks

Coal, limestone, chert, and sedimentary iron ores are basically of chemical or biochemical origin, though each contains a subordinate amount of clastic mineral matter. These rocks are closely associated with each other, and although they constitute but 4 percent of the total rock section, they form the most widespread and distinctive individual beds in the Pottsville rocks of this area.

Chemical rocks are classified on the basis of composition. Unlike the clastic rocks, they were not observed to intergrade, and if they do, it is within very short distances; there was rarely any question, where exposures were not deeply weathered, of the nature of the chemical rock. Most of the *coals* of this area are poorly banded dull attrital coals (splints or semisplints); dull nonbanded coals (cannel or canneloid) are found locally. *Limestones* are medium gray, lack observable bedding, and are very finely crystalline. Marine invertebrates of many types are found in the limestones, but their collection and identification are difficult. The Upper Mercer limestone is commonly cherty, and is in places represented only by bedded or nodular dark gray to dark yellow-brown *chert.* Chert was not found in association with any of the other limestones in the area. *Sedimentary iron ores* are rare constituents of the measured sections.

GEOGRAPHIC DISTRIBUTION OF MEMBERS

Every member of every cyclothem in the Pottsville formation is known to be absent from its predicted stratigraphic position at some place within the area studied. These absences must result from complete local cessation of deposition, contemporaneous deposition of another sediment, or deposition followed by erosion and deposition of a younger sediment. Lateral and vertical intergradation of clastic rock types can be demonstrated graphically in some of the larger exposures, but local absence of the more widespread chemical rock types, contemporary facies equivalents of which were not discovered, is not so readily explained.

The thin Middle Mercer coal and the overlying Lower Mercer limestone are among the most areally restricted chemical rock strata. They are limited for the most part to approximately 4 square miles in the southwest corner of the mapped area (fig. 1). Elsewhere in the area of study the place of this coal and limestone

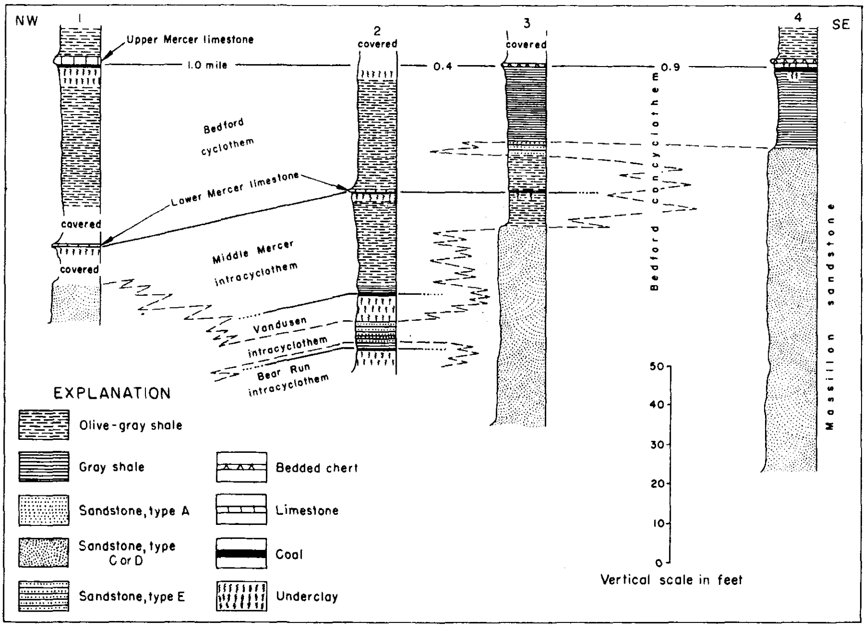

FIGURE 4. Correlated stratigraphic sections showing relation of Massillon sandstone to Lower Mercer limestone and Middle Mercer, Vandusen, and Bear Run coals. Solid correlation lines are boundaries of cyclic units; dashed lines relate sandstone bodies. Refer to figure 1 for location of measured sections.

is taken by clastic rocks, much of which is sandstone. Where thick, this sandstone is considered a part of the Massillon. Figure 4 indicates the nature of this transition where it is best seen. The coal and limestone, traced eastward from sections in which they are present in normal thickness (fig. 4, secs. 1 and 2) give way first to a thin gray shale that is underlain by a poorly developed underclay (sec. 3); this in turn is pinched out by coalescence of tongues of sandstone that lie above and below the shale (sec. 4). The exact correlation of these sandstone tongues is not certain, as exposures between sections 3 and 4 are not continuous, but scattered outcrops support the interpretation shown. Thus the top of the sandstone appears to rise stratigraphically eastward and to interfinger with the olive-gray shale that lies above the sandstone in section 3 (fig. 4); the shale apparently intervenes laterally between the sandstone body and the beds of coal and limestone.

Over a large area the main Tionesta coal has a sandstone roof (fig. 5, secs. 8 and 9). The contact between the coal and the sandstone is sharp and somewhat irregular. This suggests a disconformable relationship, but in none of the many exposures noted was this coal seen to be cut out by sandstone. Where the Tionesta coal is absent, shales most commonly are found in its place (fig. 5, sec. 6); the extent of the Tionesta coal (fig. 6, c) coincides strikingly with the area in which the part of the Brookville cyclothem below the Tionesta coal is dominantly mudrock (fig. 6, d).

The Tionesta 1 coal, which lies about 20 ft above the main Tionesta, is restricted to the south-central part of the area mapped (fig. 6, a) and lies for the most part within or adjacent to the area in which the upper part of the Brookville cyclothem is dominated by mudrocks (fig. 6, b). The Tionesta 1 coal thins and disappears northward into the area in which type A sandstones dominate the

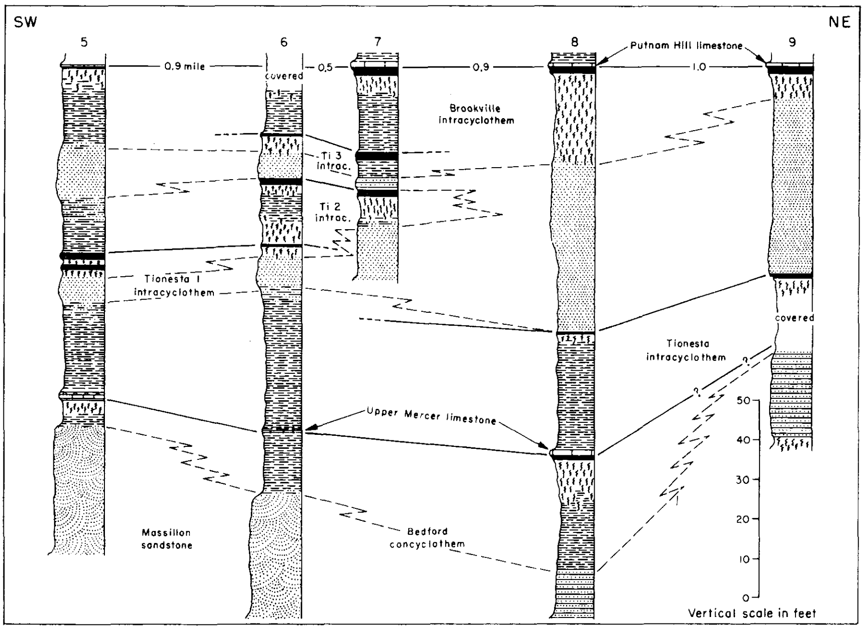

FIGURE 5. Correlated stratigraphic sections showing relations of rocks in Brookville and upper part of Bedford cyclothems. Solid correlation lines are boundaries of cyclic units; dashed lines relate sandstone bodies. Refer to figure 1 for location of measured sections.

upper Brookville. The thinning is not, however, the result of erosion (fig. 5, sec. 6); again, the top of the underlying sandstone appears to rise northeastward.

The Tionesta 2 coal has a sandstone roof, but where this coal is missing (fig. 5, sec. 5), the sandstone that takes its place has a gradational basal contact and does not suggest the filling of an erosional channel. The Tionesta 3 coal, which is of variable thickness and is restricted to a very small area, is everywhere overlain by shale (fig. 5, secs. 6 and 7). The Brookville coal ranges in thickness from 0.1 ft (fig. 5, sec. 5) to 2 ft (fig. 5, sec. 7), yet everywhere it is overlain by the very finely crystalline Putnam Hill limestone.

These examples demonstrate that thickness variations and lateral limits of the chemical rocks are not, in general, controlled by sandstone-filled erosional channels. The data instead suggest that original depositional controls are of paramount importance. Consider the close correspondence shown between the distribution of chemical rock beds and the distribution of underlying mudrocks. It is not likely that a mudrock substratum is in some way favorable to subsequent deposition of chemical rocks; it seems more probable that this relationship results from an orderly evolution of depositional environments of limited areal scope.

ORIGIN OF THE CYCLOTHEMS

The voluminous literature on the origin of cyclothems has been summarized recently by Weller (1956). None of the many hypotheses formulated to explain cyclothems has received universal approval, but the diastrophic-control theory of Weller (1930, 1956) and the glacial-eustatic theory of Wanless and Shepard (1936) are most widely known in this country. Neither of these appears applicable to the Pottsville cyclothems in this part of Ohio because each relies heavily on a widespread disconformity as evidence of emergence and subaerial erosion.

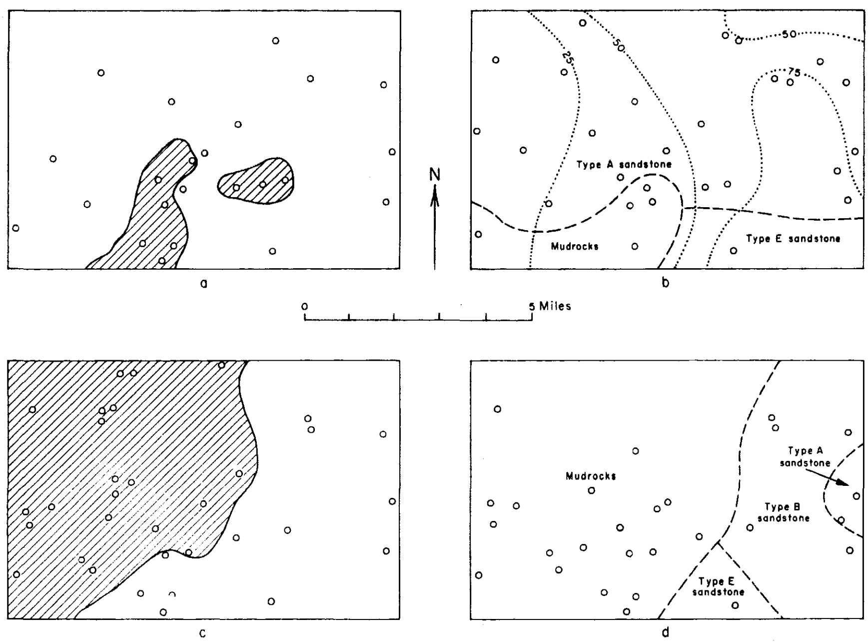

FIGURE 6. Maps showing extent of rock types in Brookville cyclothem. Area shown is same as that in figure 1. Circles indicate points of observation. a, extent of Tionesta 1 coal (ruled); b, dominant rock type in upper part of Brookville cyclothem and contours showing total sandstone content (in percent) in entire cyclothem; c, extent of main Tionesta coal (ruled); d, dominant rock type in lower part of Brookville cyclothem.

In the area studied, disconformities are commonly found, not only beneath well-developed sandstones that presumably fill channels, but within sandstone bodies as well. Between the tracts occupied by thick sandstones, in places that would necessarily have been topographically high on the old erosional surface, contacts between clastic rock bodies are characteristically transitional. It therefore seems likely that these disconformities are not continuous and do not represent regional emergence and erosion.

This does not mean that diastrophic or eustatic controls of sedimentation were inactive or ineffective in this area. Tectonic activity certainly set the determining background for Pottsville sedimentation. Eustatic adjustments of sea level, whether caused by glaciation or otherwise, no doubt acted to negate or reinforce tectonic subsidence. Any theory proposed to explain the cyclic deposition of Pottsville rocks in this area must, however, include some type of local depositional control to explain the limited areal extent of individual members of the cyclothems.

Selective Sedimentary Traps and Sedimentary Differentiation

The various rock types recognized in this study may be classified according to the mechanical energy characteristic of their inferred environment of deposition. Mechanical energies of modern environments can be measured and are an important hydrodynamic characteristic of the environment. The assignment of an older sediment to a given environment is an inference, however, and cannot be either precise or certain; therefore, only three broad groups of environmental energies, loosely and subjectively categorized, will here be used. High-energy environments include streams and beaches in which relatively coarse sediments, such as sandstone types A, B, C, and D, accumulate. Low-energy environments include slack-water flood plains, tidal flats, and lagoons, in which finer sediments, such as type E sandstones and mudrocks, are deposited. Environments so devoid of active clastic sedimentation that deposition of chemical rock types is possible may be considered to have essentially zero mechanical energy.

In general, in the Dundee area, rock types characteristic of low-energy environments intervene between high-energy rocks and zero-energy rocks, not only vertically, but also laterally. The lateral equivalence thus implied means that there was, at any given time, areal segregation of environments of different energy levels. This segregation of environments is the most characteristic feature of Pottsville paleogeography of this area. It reflects the mechanism of control over the original distribution of individual rock bodies, and made possible the local cyclic development of Pottsville sediments.

The feature proposed as a mechanism for effecting segregation of environments of different energies is the *selective sedimentary trap*, an areally restricted depositional environment that is rather sharply distinguished physically from neighboring environments (Gray, 1954). Where an abrupt change takes place in the energy or carrying capacity of a medium of transport, a selective sedimentary trap may be established. Deposition results from energy dissipation within the trap; the coarser sediments are deposited and the finer are carried through. Deposits typical of selective sedimentary traps are offshore bars and natural levees. Both develop in narrow areas between a very high-energy environment in which erosion or transportation is dominant and a low-energy environment of relatively quiet water. Both help to confine and keep separate the dissimilar environments that border the trap.

Coarse sediments collected in high-energy selective sedimentary traps are less compactible than finer-grained sediments of adjacent low-energy environments. A physiographic high favorable for sedimentary trapping is thus maintained in a generally subsiding milieu, and the trap tends to stay in the same place through a considerable span of time. Equality of sedimentation and subsidence favors development and geographic stability of selective sedimentary traps, but traps probably can survive a small or short-lived imbalance of the two processes.

Traps are highly *effective* and collect a large proportion of the sediment passing through if the rate of energy drop within the trap is high. Traps are highly *selective* and retain only a narrow range of size grades if the energy gradient is low. Most selective sedimentary traps differentiate incoming sediments into a fraction that remains in the trap and a fraction that passes through. This process is here called *sedimentary differentiation*.

The probable course of sedimentary differentiation of the clastic rocks in the area studied can be substantiated to some extent by mathematical treatment of the data in tables 1 and 2. If the D sandstones, which are coarse high-energy deposits, and the E sandstones, which are finer low-energy deposits, are combined on the basis of their observed quantity and composition, the result is a sediment remarkably similar to the C sandstones. If, therefore, sediment similar to that of the C sandstones were passed through a selective sedimentary trap of proper characteristics, it would be differentiated into D and E sandstones (fig. 7, bottom). There is physical substantiation for this process in the observed lateral

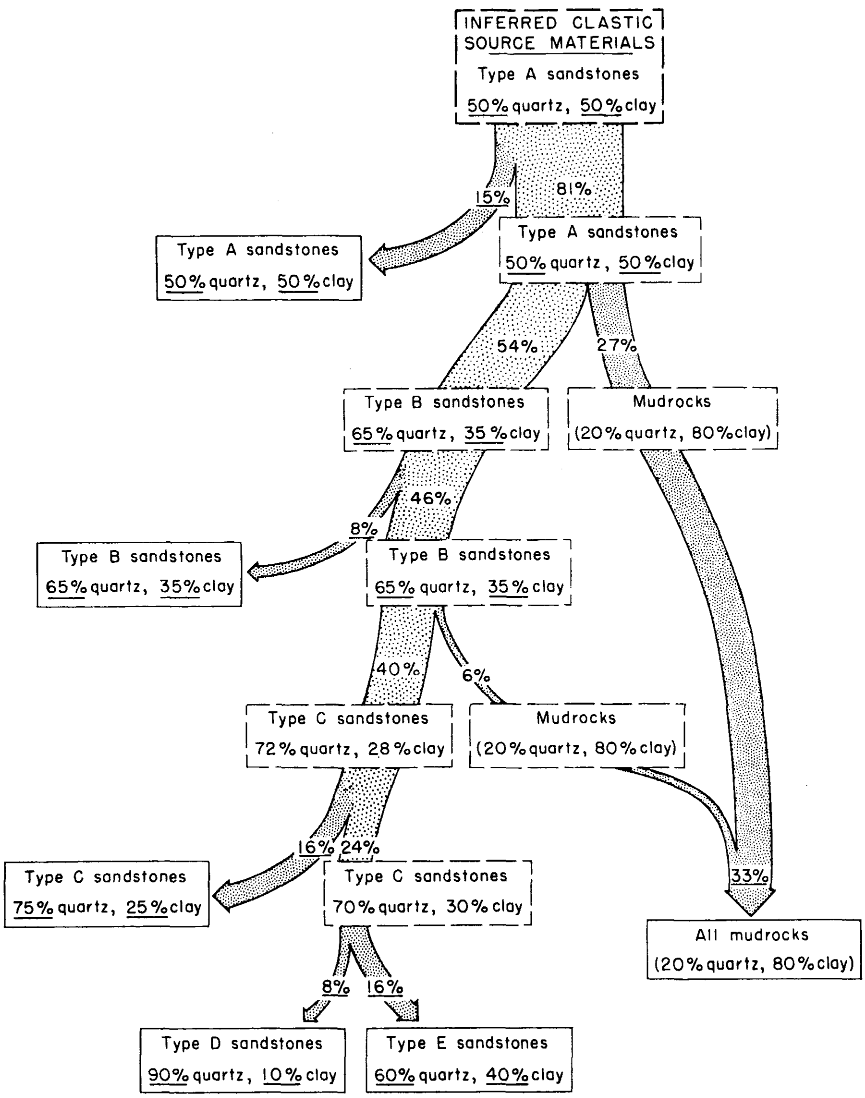

FIGURE 7. Sequence of clastic sediments formed by sedimentary differentiation in Pottsville rocks near Dundee, Ohio. Underlined figures derived or inferred from field observations; figures in parentheses assumed; all others calculated from these. Solid lines enclose observed rocks; dashed lines enclose inferred intermediate or parent sediments. Four percent of the total source material is of chemical or biochemical origin.

equivalence of these sandstone types (table 1). In like manner, the other sandstones could have been derived each from the next less quartzose sandstone type by the winnowing out of a reasonable quantity of fine constituents. By mathematical reconstitution, it can be calculated that the source material from which all the clastic rocks of this area could have been derived, by sequential differentiation in a series of selective sedimentary traps, was probably similar in composition to type A sandstone (fig. 7).

Selective Sedimentary Traps and the Deposition of Cyclothems

The particular environments represented by each of the sandstone types may be inferred from consideration of the physical characteristics of possible types of sedimentary traps. The nearly horizontal thin bedding and fair sorting of the type A sandstones suggest rather rapid deposition, possibly along natural levees and flood-plain edges. The somewhat coarser grain and relatively disorganized crossbedding of the type B sandstones perhaps reflect deposition in channel bars of aggrading streams. The oxidizing character of the environments of deposition of both sandstone types is indicated by their lack of carbonaceous material. Type

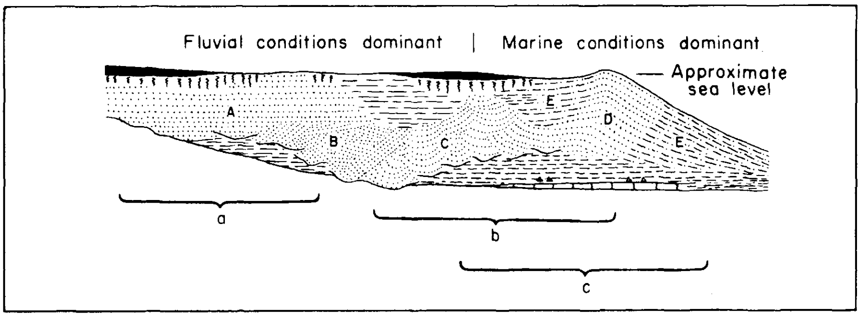

FIGURE 8. Generalized composite Pottsville-type cyclothem in profile. Length of diagram approximately 30 miles; thickness approximately 30 ft. Rock types shown in proportion to their abundance. Brackets indicate range of rock associations observed in named cyclothems within area studied; a, Brookville cyclothem; b, Bedford cyclothem; c, Middle Mercer cyclothem. Capital letters A–E designate sandstone types illustrated in figure 3 and described in table 2.

C sandstones may be delta-channel bar deposits, as suggested by the common inclusion of ferruginous and carbonaceous materials as well as by the randomly crossbedded character of these sandstones. The thoroughly worked-over, well-sorted, quartzose type D sandstones with their consistent directions of incline bedding may be deposits of beaches and offshore bars.

The E sandstones are the only type for which a precise modern analogue may be found on the basis of comparative physical characteristics. This sandstone type and its many typical small-scale sedimentary structures have been mentioned frequently in the literature of recent years (Curry and Curry, 1954; Fentress, 1955; and Shepard, 1956). There is little doubt that these are deposits of tidal flats, marine delta fronts, and aprons adjacent to offshore bars.

From a synthesis of these environmental interpretations and the known and inferred lateral relationships of the rocks in this area, a composite type cyclothem, in effect a profile drawn parallel to the depositional dip, may be assembled (fig. 8). This sequence is not seen in its entirety in any cyclothem within the area studied, but recognizable parts of it are seen, and most known vertical and lateral successions can be fitted into this general pattern. For simplicity, complications resulting from the introduction of intracyclothems and concyclothems are not shown.

A profile similarly synthesized along the depositional strike would show more gradual lateral variations, but through a much wider range of the sand-shale ratio.

In this depositional pattern it is fundamental that nearly all sedimentary types are being deposited simultaneously at one place or another, only the relative proportions being different from time to time. This is particularly true of the clastic rocks, materials for which must be delivered continually, though at times in diminished quantity, in order to maintain the trap barrier which isolates the low-energy environments in which conditions are favorable for chemical sedimentation. The necessity of a continuous clastic sediment supply required by this hypothesis even during times of widespread chemical sedimentation controverts the concept of essentially uninterrupted original sheets of homogeneous sediments called for by most other hypotheses of cyclothemic deposition, but accords well with modern analogues.

This hypothesis was formulated to account for the accumulation of cyclic assemblages of sediments in local, more or less isolated basins. Whether precise correlation between basins is possible was not determined in this study and remains to be demonstrated. All correlations involve some assumptions, and I know, at present, no way of proving exact contemporaneity of disconnected stratigraphic units that were deposited in separate basins. Such correlations may be possible if broad tectonic or eustatic controls permitted simultaneous development of traps in different areas.

LITERATURE CITED

Curry, W. H., Jr. and **W. H. Curry, III.** 1954. South Glenrock, a Wyoming stratigraphic oil field. Am. Assoc. Petroleum Geol. Bull. 38: 2119–2156.

Fentress, G. H. 1955. Little Beaver field, Colorado, a stratigraphic, structural, and sedimentation problem. Am. Assoc. Petroleum Geol. Bull. 39: 155–188.

Gray, H. H. 1954. Stratigraphy and sedimentation of Pottsville rocks near Beach City, Ohio. (unpublished Ph.D. dissertation). The Ohio State Univ. 123 p.

———. 1956. Petrology of the Massillon sandstone at the type locality. Ohio J. Sci. 56: 138–146.

Ingram, R. L. 1953. Fissility of mudrocks. Geol. Soc. Am. Bull. 64: 869–878.

Newberry, J. S. 1874. Geology of Tuscarawas County; geology of Stark County. Ohio Geol. Survey Rept. 3: 52–89, 151–176.

Shepard, F. P. 1956. Marginal sediments of Mississippi delta. Am. Assoc. Petroleum Geol. Bull. 40: 2537–2623.

Wanless, H. R. and **F. P. Shepard.** 1936. Sea level and climatic changes related to late Paleozoic cycles. Geol. Soc. Am. Bull. 47: 1177–1206.

——— and **J. M. Weller.** 1932. Correlation and extent of Pennsylvanian cyclothems. Geol. Soc. Am. Bull. 43: 1003–1016.

Weller, J. M. 1930. Cyclical sedimentation of the Pennsylvanian period and its significance. J. Geol. 38: 97–135.

———. 1956. Argument for diastrophic control of late Paleozoic cyclothems. Am. Assoc. Petroleum Geol. Bull. 40: 17–50.